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ABSTRACT

Mock Critical Peak Pricing (CPP) events were implemented in a Target retail store in the San Francisco Bay Area by shutting down some of the building's packaged rooftop air-handling units (RTUs). Measurements were made to determine how this load shedding strategy would affect the outdoor air ventilation rate and the concentrations of volatile organic compounds (VOCs) in the sales area. Ventilation rates prior to and during load shedding were measured by tracer gas decay on two days. Samples for individual VOCs, including formaldehyde and acetaldehyde, were collected from several RTUs in the morning prior to load shedding and in the late afternoon. Shutting down a portion (three of 11 and five of 12, or 27 and 42%) of the RTUs serving the sales area resulted in about a 30% reduction in ventilation, producing values of 0.50-0.65 air changes per hour. VOCs with the highest concentrations (>10 μg/m^3) in the sales area included formaldehyde, 2-butoxyethanol, toluene and decamethylcyclopentasiloxane. Substantial differences in concentrations were observed among RTUs. Concentrations of most VOCs increased during a single mock CPP event, and the median increase was somewhat higher than the fractional decrease in the ventilation rate. There are few guidelines for evaluating indoor VOC concentrations. For formaldehyde, maximum concentrations measured in the store during the event were below guidelines intended to protect the general public from acute health risks.

INTRODUCTION

One readily available method of reducing peak electrical demands (technically termed "load shedding") in a building is to temporarily reduce the rate of outdoor air supply (i.e., the ventilation rate). This strategy should diminish summer-time peak electrical demands because, during hot weather, considerably less energy is required to cool and dehumidify recirculated indoor air than to condition outdoor air. Another convenient method to reduce peak demand is to allow indoor temperatures to exceed the normal indoor temperature set point. Target Corporation participated in a Critical Peak Pricing (CPP) study (Piette, 2005) and agreed to evaluate the effectiveness of ventilation rate reduction to decrease peak electrical loads during the summer of 2005 at a store in the San Francisco Bay Area. However, there was a concern about the potential adverse impacts of these measures on indoor air quality (IAQ). This concern naturally arises because indoor concentrations of many indoor generated air pollutants, such as volatile organic compounds (VOCs), are predicted to increase when rates of outdoor air supply are decreased. Due to the near total absence of data on VOCs and other indoor pollutant concentrations in retail environments, we were unable to predict whether temporary increases in indoor pollutant levels were likely to exceed typical values for other non-residential buildings or guidelines for short-term exposures. Thus, we designed this pilot study to investigate how load shedding in a single Target store, accomplished by shutting off a portion of the rooftop air-handling units, would affect the outdoor air ventilation rates and the concentrations of VOC air contaminants in the store's sales area.

METHODS

This pilot field study took place at a general merchandise discount store operated by Target Corporation. The store is located in the San Francisco Bay Area. The single story structure has a total floor area of approximately 12,100 m^2 (130,000 ft^2). The sales area, with an area of 10,200 m^2 (110,000 ft^2) and a dropped ceiling height of 4.3 m (14 ft), is divided into numerous departments such as Health and Beauty, Home Furnishings, Domestics, Sporting Goods, etc. The building also contains offices, a public restaurant area, and a stocking area. Building air is supplied and conditioned by 23 packaged and individually ducted rooftop air-handling units (RTUs), 12 of which serve the sales area. These RTUs are remotely programmed and operated from Target Corp. headquarters in Minneapolis, MN. Target routinely monitors and records fan status, compressor settings, and indoor air temperatures. For this study, mock CPP events were implemented. On specified dates, all RTUs were to be on and operating in a non-economizer mode in the morning beginning at 8:00 am. The mock "Shed" period was to begin at noon. The plan called for five RTUs in the sales area to be shut down completely during this period from 12:00 to 18:00. As an additional load shedding measure, 25 percent of the lights in the sales area were to be turned off from 15:00 to 18:00. The first experiment (Exp 1) was conducted on October 6, 2005, and the second experiment (Exp 2) was conducted on October 25, 2005.

Measurement of the ventilation rate in the sales area was performed by a tracer gas decay technique. Perfluoro(methylcyclohexane) 90% technical grade (PMCH, CAS No. 35502-2) was used as the tracer compound. At 9:00 am on the days of the experiments, liquid PMCH was injected into glass dishes positioned inside RTUs 8 and 12 serving the sales area. The liquid quickly evaporated providing a near-pulse injection. For Exp 1, 1 mL of PMCH was injected into each of the two RTUs; for Exp 2, 1.5 mL was injected into each of the two RTUs. Air samples for the tracer compound and air contaminants (see below) were collected from RTUs 11, 13 and 15 selected for their distribution across the sales area. A 2-m section of 6.4-mm OD FPA Teflon® tubing was inserted into the return air duct of each sampled RTU. This tubing was connected to a stainless-steel manifold positioned outside the duct and to a downstream vacuum pump, which maintained an approximate 4-L/min airflow rate through the tubing and manifold. Air samples for the analysis of the tracer compound periodically were collected from the vacuum pump outlets into clean gas sampling bags. In Exp 1, valid samples only could be obtained from RTUs 11 and 13 due to a mechanical problem with the manifold system on RTU 15. In addition, sampling on this date did not begin until 11:00, with six samples collected from each of the two RTUs in the Pre-shed period between 11:00 and 12:00. An additional six samples were collected from each RTU during the Shed period from 12:00 to 14:00. In Exp 2, samples were collected at approximately 20-min time intervals between 10:00 and 14:00 from all three RTUs, resulting in a total of 36 samples. Samples were analyzed within several days of their collection by gas chromatography employing an electron capture detector and a proprietary column (Autotrac, Lagus Applied Technology, Inc.).

Air samples for the analysis of VOCs and low molecular weight aldehydes also were collected. Sampling systems consisted of electronic mass flow controllers and vacuum pumps.

These were used to obtain duplicate VOC samples and a single aldehyde sample from the sampling manifold at each RTU during the Pre-shed and Shed periods. VOC gas samples are collected onto Tenax®-TA sorbent tubes (CP-16251, Varian Inc.) modified by substituting a 15-mm section of Carbosieve S-III 60/80 mesh (10184, Supelco Inc.) at the outlet end. Aldehyde samples were collected on treated, 2,4-dinitrophenylhydrazine (DNPH), silica-gel cartridges (WAT047205, Waters Corp.). Samples were collected from the return air ducts of RTUs 11, 13 and 15 at the end of the Pre-shed period from 11:00 to 12:00 and near the end of the Shed period from 16:00 to 17:00. These time periods were selected so comparisons could be made assuming quasi steady-state conditions. As noted above, the samples obtained from RTU 15 in Exp 1 were compromised by a mechanical problem and were discarded. Sample volumes were approximately 3 L for VOCs and 30 L for aldehydes.

An additional set of air samples for VOCs and aldehydes was collected during a preliminary walk-through survey conducted at mid morning on July 29, 2005. A researcher carried the sampling equipment consisting of battery-operated pumps and the sampling media described above in a backpack and slowly walked through the aisles over a 30-min period. The VOC sample volumes were 1.8 L; and the aldehyde sample volume was 32 L.

The VOC samples were analyzed for individual compounds by thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS) generally following U.S. EPA Method TO-1 (U.S. EPA, 1984). A field blank and several duplicate samples were analyzed for each experiment. The aldehyde samples were extracted and analyzed for formaldehyde and acetaldehyde by high performance liquid chromatography with UV detection following ASTM standard method D-5197-97 (ASTM, 1997). For data analysis, VOC masses were first corrected for any associated blank values then concentrations in micrograms per cubic meter (µg/m3) were calculated. Concentrations for duplicate VOC samples collected at a location were averaged. Detection limits were about 0.3 $\mu g/m^3$ for VOCs and 1 $\mu g/m^3$ for aldehydes.

RESULTS AND DISCUSSION

Ventilation Rate

The ventilation rate results are presented in Table 1. For Exp 1, Target's fan status record indicated that one of the 12 RTUs in the sales area was not functioning throughout both the Pre-shed and Shed periods. In addition, only three RTUs of the remaining four units were shut down during the Shed period instead of the originally planned five units. For this experiment, the average Pre-shed air change rate calculated from the data obtained from RTUs 11 and 13 was 0.71 h^{-1}. There was substantial variability in the PMCH concentrations measured for RTU 13 during the early portion of the Shed period as indicated by the low coefficient of determination for the linear regression of the natural log of the tracer gas concentration versus time ($r^2 = 0.62$). However, elimination of these points resulted in a similar slope. Using all data points, the average ventilation rate during the Exp 1 Shed period was 0.50 h^{-1}, indicating a 29% reduction in outdoor air supply consistent with the shutdown of three of 11 RTUs. For Exp 2, the coefficients of determination for the linear regressions were 0.96 to 1.0. The average Pre-shed ventilation rate on this date with all 12 RTUs operational was 0.95 h^{-1}. With the onset of the Shed period and the shutdown of five RTUs, the average ventilation rate decreased by 31% to 0.65 h^{-1}. This was approximately the same percentage reduction observed during Exp 1.

The guideline for the minimum average ventilation rate in the sales area of a retail environment under versions 62-1989 through 62-2001 of the ASHRAE ventilation standard was 5.49 m^3/h per square meter of floor area (300 cfm/1000 ft^2). The corresponding minimum ventilation rate in the latest ASHRAE 62.1-2004 standard (ASHRAE, 2004) is 4.25 m^3/h-m^2 (232 cfm/1000 ft^2), or 22% lower, as determined by a calculation using the estimated occupancy (15 people/1000 ft^2 with 7.5 cfm/person) and the retail square foot value (0.12 cfm/ft^2) from Table 6-1 of the document. The most recent California Title 24 minimum ventilation rate for retail stores (CEC, 2005) is slightly higher at 4.57 m^3/h-m^2 (0.25 cfm/ft^2) as specified in Table 4-2 of the document. The caveat, here, is that Title 24 requires continuous ventilation at this minimum rate. Given the ceiling height of the sales area of about 4.3 m (14 ft), the minimum average ventilation rate specification is 1.0 air changes per hour (ACH, h^{-1}) under the current ASHRAE guideline and 1.1 h^{-}1 under the current Title 24 guideline. In Exp 2 with all 12 RTUs operational, the ventilation rate approached the ASHRAE guideline. However, the Pre-shed ventilation rate measured in Exp 1 and the Shed period values from both experiments were below both guidelines.

Concentrations of Air Contaminants

The concentrations of VOCs (μg/m^3) measured on the sales floor during the preliminary walk-through survey are presented in Table 2. There were 34 quantified compounds for this sampling event including formaldehyde and acetaldehyde. The compounds with the highest concentrations (>10 μg/m^3) were formaldehyde, 2-butoxyethanol (2-BE), toluene and decamethylcyclopentasiloxane (D5 siloxane). Formaldehyde is emitted by a variety of sources that may be present in this retail environment. These sources include composite wood products such as particleboard and medium density fiberboard, fabrics, and cardboard packaging (Kelly et al., 2001). Toluene is a ubiquitous outdoor air contaminant derived from motor vehicle exhaust and gasoline evaporative emissions. It may be used as a solvent in flooring adhesives (Hodgson, 1999) and other products used indoors. 2-BE is used as a solvent in a number of consumer products including disinfectants, general-purpose cleaners, glass cleaners and spot removers (Nazaroff and Weschler, 2004; Zhu et al., 2001). D5 siloxane is used in underarm deodorant products and likely is emitted by other silicone containing products. The remaining VOCs, which occurred at lower concentrations, also are commonly encountered indoor air contaminants (Hodgson and Levin, 2003).

For Exp 1, a total of 36 VOCs including formaldehyde and acetaldehyde were quantified. The combined precision for the sampling and analysis of many of the same VOCs and aldehydes at similar concentrations was determined in a recent study using the identical sampling equipment and analytical instrumentation (Hodgson et al., 2005). Typically, precision measured as a relative standard deviation was about ±4% (range <1-11%). The predominant compounds in Exp 1 (>10 μg/m^3) were formaldehyde, acetaldehyde, acetone, ethanol, 2-BE, di(propylene glycol)methyl ethers (DPGME), and toluene. For some compounds, concentrations measured in the returns of the two RTUs varied by more than a factor of two indicating substantial spatial variability. Thus, the Pre-shed and Shed concentrations are compared by RTU in Table 3. The concentrations of 22 of the quantified VOCs increased by more than ten percent from the Pre-shed to the Shed period at RTU 11. The fractional increases ranged from 0.11 to 1.28, and the median increase was 0.41. Formaldehyde increased by a factor of 1.12. At RTU 13, the concentrations of 28 VOCs increased in the Shed period. The fractional increases ranged from 0.15 to 1.70, and the median increase was 0.65. The concentrations of isopropanol and acetone substantially decreased at both locations. These two compounds are common constituents of cleaning products and may have derived from janitorial activities early in the day. Average fractional changes are shown in Table 3 for VOCs for which the direction of change was consistent between the two RTUs. In general, the typical fractional increases in VOC concentrations at the RTUs are higher than the uncertainties in the measurements and somewhat larger than are predicted by the fractional decreases in the ventilation rates (Table 1).

In Exp 2, the five RTUs were shut off at noon at the start of the Shed period as planned. However, they were restarted at 1:00 pm, possibly due to miscommunication with the central control station. This situation was unknown to the field personnel conducting the experiment. Thus, no information on the effect of load shedding on VOC concentrations was obtained on this date. Instead, the data were used to assess VOC concentrations for the store (Table 4). Thirty-four VOCs were quantified. The predominant compounds (geometric mean >10 $\mu g/m^3$) were formaldehyde, 2-BE, DPGME and toluene. At each of the three locations, the concentrations measured in the late morning and late afternoon generally were similar with several exceptions. There were clear and consistent decreases in the concentrations of 2-BE and DPGME. At noted above, 2-BE is contained in various cleaning products and may have been associated with janitorial activities. The source of DPGME is unknown. For compounds measured at more than one location, the concentration data are summarized as geometric means and standard deviations (Table 4). With the exceptions of the higher concentrations of 2-BE, DPGME and tetrachloroethene on this date, the concentrations generally are consistent with the concentrations measured on the two prior occasions.

To our knowledge, there are no studies published in the peer-reviewed literature giving indoor VOC concentrations and/or exposures for North American retail environments. One relevant study presented as a conference poster (Loh et al., 2004) reported geometric mean concentrations for 12 non-residential microenvironments including department stores and multipurpose stores (not further defined). Generally, there were nine to 13 stores in a microenvironment category assigned across seven composite samples, each collected and analyzed in triplicate. Results were presented for five VOCs also quantified in the Target store (formaldehyde, acetaldehyde, toluene, dichloromethane, and tetrachloroethene). Approximate geometric mean concentrations ($\mu g/m^3$) read from bar graphs are reproduced in Table 5. The average concentrations measured during Exp 2 when compared to this multi-building survey are similar for formaldehyde and acetaldehyde, lower for toluene and dichloromethane, and higher for tetrachloroethene.

Eleven of the VOCs measured in the Target store on the three sampling occasions have guidelines for acceptable exposures to protect the general population, including sensitive individuals, from acute and chronic noncancer health effects (ATSDR, 2003; OEHHA, 2005). These are conservative values meant to serve as screening tools for public health officials. Generally, they are substantially lower than industrial workplace guidelines. The agencies assume that exposures are continuous over the specified time periods. For example, the chronic Reference Exposure Levels developed by the California Office of Environmental Health Hazard Assessment (OEHHA, 2005) assume an exposure period of ten years or more. Among the 11 compounds, only the concentrations of formaldehyde, acetaldehyde, naphthalene and tetrachloroethene are within a factor of ten of any guideline values. In Table 6, the maximum measured concentrations of these compounds on the three sampling occasions are compared to acute guidelines and their geometric mean concentrations measured in Exp 2 are compared to chronic guidelines.

Maximum formaldehyde concentrations measured in the store are below the more restrictive ATSDR acute (1- to 14-day) Minimal Risk Level of 50 $\mu g/m^3$. The California Air Resources Board recently has recommended a maximum formaldehyde concentration of 33 $\mu g/m^3$ (27 ppb) for eight-hour exposures in residences and schools (CARB, 2004). The maximum formaldehyde concentrations in the store approach, but are below, this lower guideline. Geometric mean formaldehyde and acetaldehyde concentrations both exceed their chronic exposure guidelines. However, as noted, these guidelines assume continuous exposure over the time periods of interest. In addition, the formaldehyde chronic REL is at or near concentrations measured in urban outdoor air. Thus, formaldehyde, and likely acetaldehyde, exposure concentrations exceed their chronic RELs in many indoor environments.

In the virtual absence of data for retail environments, VOC concentrations measured in the store can be compared with concentrations for office buildings. Formaldehyde and acetaldehyde concentrations have been summarized for a set of 100 U.S. office buildings (Apte and Erdmann, 2003). Average (± one standard deviation) formaldehyde concentrations were 16 ± 8 $\mu g/m^3$; average acetaldehyde concentrations were 8 ± 4 $\mu g/m^3$. Thus, the concentrations of these two compounds in the store are consistent with concentrations reported for this other important non-residential environment.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This study provided data on the concentrations of a number of VOC air contaminants in a large general merchandise discount store. Such data previously were unavailable. For some compounds, substantial spatial variability (i.e., a factor of two or more) was observed among concentrations measured at several rooftop air-handling units. However, the results generally were consistent across all three sampling events, which included an integrated sample obtained while walking through the aisles of the various sales departments. The measured concentrations generally were low in comparison with concentrations in other buildings and in comparison with conservative short-term exposure guidelines. In addition, ventilation rates were measured. These measurements indicated the store was operating in non-shed mode near the current ASHRAE and California Title 24 ventilation guidelines for retail environments.

Information obtained on the effects of peak electrical load shedding implemented by deactivating a fraction of the rooftop air-handling units was limited to a single mock CPP event. When three of 11 air-handling units in the sales area were turned off, the ventilation rate measured in the sales area decreased by about 30%. Concentrations of a number of air contaminants measured near the end of the load-shedding period increased as expected in response to the ventilation rate change. The magnitudes of the increases varied substantially, likely as the result of a number of factors including changes in contaminant emission rates from primary sources both dependent and independent of the ventilation rate change, and secondary effects related to ventilation such as higher sorption of contaminants to surfaces at higher air concentrations. Typical increases in concentrations were somewhat higher than the corresponding decrease in the ventilation rate.

Considering this was a limited study of a single store, we cannot draw general conclusions about the potential indoor air quality impacts of ventilation rate reductions in large retail buildings. However, VOCs are an important component of the indoor air pollutants of concern in the retail environment. Thus, the generally low concentrations of these compounds measured during the study are encouraging. Further research clearly is needed to characterize ventilation rates and the concentrations of VOCs, including formaldehyde and acetaldehyde, across a number of large retail stores. If such research determines that VOC concentrations are low relative to concentrations in other building types and are acceptable with respect to exposure guidelines, there is a potential to implement load shedding for CPP through ventilation rate reductions. However, the California Title 24 requirement for continuous ventilation at or above the minimum rate must be addressed. Conceivably, such research may point to other opportunities for statewide energy savings through more general reductions in ventilation rates in large retail buildings.

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Table 1. Ventilation rates in air changes per hour (ACH, h^{-1}) determined by tracer gas decay at three rooftop air-handling units (RTUs) for Pre-shed and Shed periods of two mock load shedding experiments.

	Ventilation Rate (h^{-1})			
	Experiment 1		Experiment 2	
RTU No.	**Pre-shed**	**Shed**	**Pre-Shed**	**Shed**
11	0.68 (r^2=1.00)*	0.53 (r^2=0.87)	0.94 (r^2=1.00)	0.65 (r^2=0.98)
13	0.74 (r^2=0.99)	0.47 (r^2=0.62)	0.89 (r^2=1.00)	0.69 (r^2=0.96)
15	---	---	1.03 (r^2=0.99)	0.62 (r^2=0.98)
Average	0.71	0.50	0.95	0.65
Difference		*-29%*		*-31%*

*ACH determined as the slope of a least-squares linear regression of the natural log of tracer gas concentrations versus time in hours. Outdoor concentrations were below the detection limit. Coefficient of determination (r^2) for the regression is shown in parentheses.

Table 2. VOC concentrations (μg/m^3) measured on the sales floor during walk-through survey conducted on July 29, 2005. In this and subsequent tables, compounds are grouped by chemical class and listed by decreasing volatility within class.

Compound	**Chemical Class**	**Conc. (μg/m^3)**
Formaldehyde	Aldehyde	21
Acetaldehyde	Aldehyde	8.9
Pentanal	Aldehyde	1.8
Hexanal	Aldehyde	4.8
Benzaldehyde	Aldehyde	4.4
Octanal	Aldehyde	2.0
Acetone	Ketone	2.1
2-Butanone	Ketone	2.6
Methyl isobutyl ketone	Ketone	0.7
Ethanol	Alcohol	7.0
Isopropanol	Alcohol	0.8
1-Butanol	Alcohol	6.6
2-Ethyl-1-hexanol	Alcohol	3.0
Phenol	Alcohol	2.7
Butylated hydroxytoluene	Alcohol	0.9
2-Butoxyethanol	Glycol	30
DPGME*	Glycol	5.3
Butyl acetate	Ester	2.8
TMPD-MIB*	Ester	1.2
TMPD-DIB*	Ester	6.6
d-Limonene	Terpene HC	3.9
Toluene	Aromatic HC	21
m/p-Xylene	Aromatic HC	5.5
1,2,4-Trimethylbenzene	Aromatic HC	1.2
Naphthalene	Aromatic HC	0.9
n-Nonane	Alkane HC	0.7
n-Decane	Alkane HC	0.4
n-Undecane	Alkane HC	1.1
n-Dodecane	Alkane HC	1.1
Freon 11	Halo HC	2.2
Tetrachloroethene	Halo HC	0.4
1,4-Dichlorobenzene	Halo HC	0.4
D5 Siloxane*	Misc.	17.7
Benzothiazole	Misc.	0.6

*DPGME = di(propylene glycol)methyl ethers; TMPD-MIB = 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (combined isomers); TMPD-DIB = 2,2,4-trimethyl-1,3-pentanediol diisobutyrate; D5 siloxane = decamethylcyclopentasiloxane.

Table 3. VOC concentrations (µg/m^3) measured at RTUs 11 and 13 near ends of Pre-shed and Shed periods of Experiment 1 conducted on October 6, 2005. Fractional concentration changes are for Shed period versus Pre-shed period. Average fractional change is shown if the direction of change was consistent at both RTUs.

Compound	RTU 11 Pre-shed (µg/m^3)	RTU 11 Shed (µg/m^3)	RTU 11 Fract. Change	RTU 13 Pre-shed (µg/m^3)	RTU 13 Shed (µg/m^3)	RTU 13 Fract Change	Avg. Fract. Change
Formaldehyde	11.5	25	1.12	18.2	24	0.32	0.72
Acetaldehyde	10.1	13.6	0.36	11.9	11.7	-0.02	
Pentanal	2.2	1.5	-0.30	0.9	1.6	0.77	
Hexanal	5.1	3.5	-0.32	1.7	3.8	1.17	
Benzaldehyde	4.1	4.7	0.16	4.2	5.2	0.24	0.20
Octanal	2.3	2.8	0.26				
Acetone	10.5	5.1	-0.51	9.1	6.7	-0.27	-0.39
2-Butanone	1.8	1.9	0.05	1.9	2.3	0.23	0.14
Methyl isobutyl ketone	0.4	0.4		0.4	0.6	0.45	0.45
Acetophenone	0.8	1.9	1.28	0.6	1.2	0.87	1.08
Ethanol	17.6	17.0	-0.03	24	36	0.48	
Isopropanol	4.0	1.2	-0.72	8.1	2.2	-0.73	-0.72
1-Butanol	2.3	3.8	0.66	2.6	5.1	0.99	0.83
2-Ethyl-1-hexanol	1.1	1.8	0.67	1.4	2.6	0.83	0.75
Phenol	1.3	1.8	0.36	1.1	2.2	1.03	0.69
Butylated hydroxytoluene		0.3			0.4		
2-Butoxyethanol	21	25	0.19	26	34	0.30	0.25
DPGME	10.1	16.5	0.64	15.7	27	0.73	0.69
Di(ethylene glycol) butyl ether		1.6		1.0	2.7	1.70	
Butyl acetate	1.1	1.4	0.34	1.3	2.0	0.52	0.43
TMPD-DIB	2.0	2.9	0.45		3.9		
d-Limonene	1.8	2.9	0.58	3.0	5.8	0.94	0.76
Toluene	11.1	15.9	0.44	11.7	18.4	0.56	0.50
m/p-Xylene	2.8	3.2	0.17	3.3	4.4	0.33	0.25
1,2,4-Trimethylbenzene	0.7	0.8	0.11	0.9	1.1	0.31	0.21
Naphthalene		0.4		0.3	0.5	0.63	
n-Nonane	0.6	0.6		0.5	0.8	0.43	0.43
n-Decane	0.6	1.4	1.21	1.1	2.5	1.21	1.21
n-Undecane	0.8	1.4	0.72	1.1	2.2	0.96	0.84
n-Dodecane	0.4	0.6	0.38	0.5	1.0	0.87	0.62
Freon 11	3.9	2.2	-0.45	0.8	1.3	0.68	
Methylene chloride	0.5	0.6	0.30	0.5	0.5	0.15	0.23
1,1,1-Trichloroethane	0.4	0.5	0.12				
1,4-Dichlorobenzene				0.4	0.6	0.56	
D5 Siloxane	5.5	11.1	1.02	6.6	15.9	1.39	1.21
1-Methyl-2-pyrrolidinone		0.3			0.3		

Table 4. VOC concentrations (μg/m3) measured at RTUs 11, 13 and 15 in the late morning (am) and late afternoon (pm) on October 25, 2005.

	Concentration (μg/m^3)						
	RTU 11		RTU 13		RTU 15		Geometric
Compound	**am**	**pm**	**am**	**pm**	**am**	**pm**	**Mean***
Formaldehyde	18.2	19.6	16.4	16.6	13.0	13.8	16.1 (1.2)
Acetaldehyde	11.0	7.3	4.9	5.6	4.8	4.9	6.1 (1.4)
Pentanal	1.2	1.0	1.6	1.5	0.8	1.2	1.2 (1.3)
Hexanal	2.9	2.6	3.7	4.2	1.9	3.3	3.0 (1.3)
Benzaldehyde	7.0	6.7	8.3	7.9	5.9	3.9	6.4 (1.3)
Octanal	1.3	1.1	1.3	1.5	0.7	1.2	1.2 (1.3)
2-Propanone	1.5	0.8	5.6	1.3	2.0	1.6	1.7 (1.9)
2-Butanone	1.9	1.1	4.6	1.5	1.3	1.7	1.8 (1.7)
Methyl isobutyl ketone			0.4	0.4		0.5	0.4 (1.2)
Acetophenone	4.4	3.9	3.2	3.6	1.9	0.6	2.5 (2.1)
Ethanol	1.2	2.6	4.3	6.3	1.4	3.4	2.7 (1.9)
Isopropanol	0.7		3.8	0.5	1.7		1.2 (2.4)
1-Butanol	2.4	2.6	5.1	4.6	2.1	3.0	3.1 (1.4)
Phenol	2.3	2.5	2.7	3.1	1.5	1.4	2.2 (1.4)
2-Butoxyethanol	39	27	101	58	59	35	48 (1.6)
DPGME	77	53	174	123	99	85	95 (1.5)
Di(ethylene glycol) butyl ether	1.2	1.4	2.6	2.7	1.2	1.7	1.7 (1.5)
Butyl acetate	0.9	1.2	1.8	2.0	1.2	1.4	1.4 (1.4)
TMPD-DIB	2.0	2.4	3.9	4.2	1.9	2.4	2.7 (1.4)
d-Limonene	5.8	2.8	8.1	5.7	2.5	2.6	4.1 (1.7)
Toluene	10.9	10.4	21	18.9	5.8	13.1	12.3 (1.6)
m/p-Xylene	1.7	1.9	3.6	3.4	1.9	2.3	2.4 (1.4)
1,2,4-Trimethylbenzene	0.5	0.5	0.9	0.8	0.4	0.5	0.6 (1.4)
Naphthalene		0.3	0.6	0.6		0.3	0.4 (1.4)
n-Nonane	0.8	0.9	1.9	1.2	0.5	0.8	0.9 (1.6)
n-Decane	0.6	0.5	1.5	1.1	0.1	0.8	0.6 (2.3)
n-Undecane	0.6	0.7	1.2	1.1	0.5	0.7	0.7 (1.5)
n-Dodecane	0.4	0.5	0.9	0.9	0.5	0.8	0.6 (1.4)
Freon 11	1.4	1.0	1.8	2.5	0.9	1.9	1.5 (1.5)
Tetrachloroethene	4.3	1.9	10.0	3.8	3.9	2.0	3.7 (1.8)
1,4-Dichlorobenzene			0.4	0.8	0.5	0.4	0.5 (1.3)
D5 Siloxane	8.8	9.4	14.7	13.8	6.1	6.8	9.4 (1.4)
1-Methyl-2-pyrrolidinone			0.5	0.3			0.4
Benzothiazole			0.3	0.3			0.3

*Geometric mean with geometric standard deviation in parentheses.

Table 5. Geometric mean concentrations (μg/m^3) of five VOCs reported by Loh et al. (2004) for composite air samples collected in department stores and multipurpose stores. Values were read and interpreted from three-dimensional bar graphs and are approximate.

	Geometric Mean Concentration (μg/m^3)	
Compound	**Department Stores**	**Multipurpose Stores**
Formaldehyde	12	16
Acetaldehyde	8	9
Toluene	52	66
Methylene chloride	1.5	4
Tetrachloroethene	2	1.2

Table 6. Acute and Chronic noncancer guideline concentrations for exposures of the general public, including sensitive individuals, to selected toxic air contaminants. Maximum concentrations of VOCs measured in the store on three occasions are compared to acute Minimal Risk Levels (MRLs) (ATSDR, 2003) and acute Reference Exposure Levels (RELs) (OEHHA, 2005). Geometric mean concentrations of these VOCs measured on October 25, 2005 are compared to chronic MRLs (ATSDR, 2003) and chronic RELs (OEHHA, 2005). Exposures are assumed to be continuous over the indicated time periods of interest.

	Concentration (μg/m^3)					
Compound	**Acute MRL 1-14 days**	**Acute REL 1 hour**	**Max. Conc.**	**Chronic MRL >365 days**	**Chronic REL >10 years**	**GeoMean Conc.**
Formaldehyde	50	94	25	10	3	16.1
Acetaldehyde	---	---	13.6	---	9	6.1
Naphthalene	---	---	0.9	4	9	0.4
Tetrachloroethene	1,400	20,000	10.0	270	35	3.7